A PILOT SURVEY TO MEASURE ANNUAL MORTALITY OF PONDEROSA PINE CAUSED BY THE MOUNTAIN PINE BEETLE IN THE BLACK HILLS OF SOUTH DAKOTA AND WYOMING 1977

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FOREST INSECT AND DISEASE MANAGEMENT
STATE AND PRIVATE FORESTRY
ROCKY MOUNTAIN REGION
11177 W. 8TH AVENUE
LAKEWOOD, COLORADO 80225

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A PILOT SURVEY TO MEASURE ANNUAL MORTALITY OF PONDEROSA PINE CAUSED BY THE MOUNTAIN PINE BEETLE IN THE BLACK HILLS OF SOUTH DAKOTA AND WYOMING 1977

by

Bruce B. Hostetler
Entomologist, Rocky Mountain Region,
USDA Forest Service, Lakewood, Colorado

and

Robert W. Young
Biometrician, Methods Application Group,
USDA Forest Service, Davis, California

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INTRODUCTION

In the western United States bark beetles cause more coniferous tree mortality than any other insect group or any disease. Improved survey methods are being established to determine extent of beetle-caused tree mortality and damage. Accurate and timely information of this sort is a necessity for forest managers and program managers to help them determine the best possible long- and short-term management goals for forested areas.

Pilot surveys of annual tree mortality caused by the mountain pine beetle (*Dendroctonus ponderosae* Hopkins) were conducted in two areas during 1977. Ponderosa pine (*Pinus ponderosa* Laws.) was surveyed on the Black Hills in South Dakota and Wyoming, and lodgepole pine (*P. contorta* var. *latifolia* Engelm.) was surveyed on the Targhee National Forest in Idaho. Reported here are results of the Black Hills survey.

The objectives of the Black Hills survey were: (1) to evaluate a multistage survey technique designed to measure annual ponderosa pine mortality caused by the mountain pine beetle (MPB) and (2) to measure total tree mortality. A secondary objective was to estimate the ratio of trees attacked by MPB in 1976 to those attacked in 1977.

DESCRIPTION OF SURVEY SITE

The initial 1977 survey involved about 1.5 million acres (0.61 million ha) of ponderosa pine (*Pinus ponderosa* Laws.) in the Black Hills of southwestern South Dakota and eastern Wyoming and the Bear Lodge Mountains of northeastern Wyoming. Most of the timber is found on two types of geologic areas: (1) a central, crystalline area characterized by rough to rounded hills and divides with elevations ranging from 4,300 to 7,000 ft (1,310 to 2,130 m) and (2) a quite extensive limestone plateau on the western side consisting of rather level divides separated by narrow, steep valleys with elevations ranging from 4,500 ft (1,370 m) to slightly over 7,000 ft (2,130 m).

Ponderosa pine is the dominant tree species in the survey area with interspersed aspen (*Populus tremuloides* Michx.), white spruce (*Picea glauca* (Moench)), white birch (*Betula papyrifera* Marsh.) and bur oak (*Quercus macrocarpa* Michx.).

The area surveyed is principally within the Black Hills National Forest with intermingled and adjoining lands owned and/or administered by the Bureau of Land Management, South Dakota State Division of Forestry, Wyoming State Forestry Division, the National Park Service, or private concerns.

METHODS AND MATERIALS

Survey Design

Stratified double sampling was used as the basic survey design. Stratification was done utilizing aerial sketch mapping followed by large scale (1:6,000) color aerial photography of each stratum and then ground truth measurements. The randomly selected ground samples allowed adjustment of the photo samples by linear regression for numbers and volume of trees killed. Additional measurements were made in each ground plot using variable plot clusters to determine the basal area ratio of residual live to dead trees. The ratio of 1976- to 1977-attacked trees was also recorded.

A time table of significant events of the survey is shown in Appendix A.

Aerial Sketch Mapping

When an estimated 95% of the 1976-attacked trees showed obvious fading (i.e., discoloration), the survey areas were sketch mapped from a light aircraft at a maximum height of 1500 ft (460 m) above the terrain. Sketching was done on a 1:126,720 scale planimetric map.

The number of discolored ponderosa pine was estimated in each of 1,025 polygons or areas (Fig. 1) delineated during sketch mapping. Polygon boundaries were made of readily visible terrain features. Approximately 26 hours of flying were required to map about 1.9 million acres (0.8 million ha). The sketch mapped polygon boundaries were then traced onto mylar overlays.

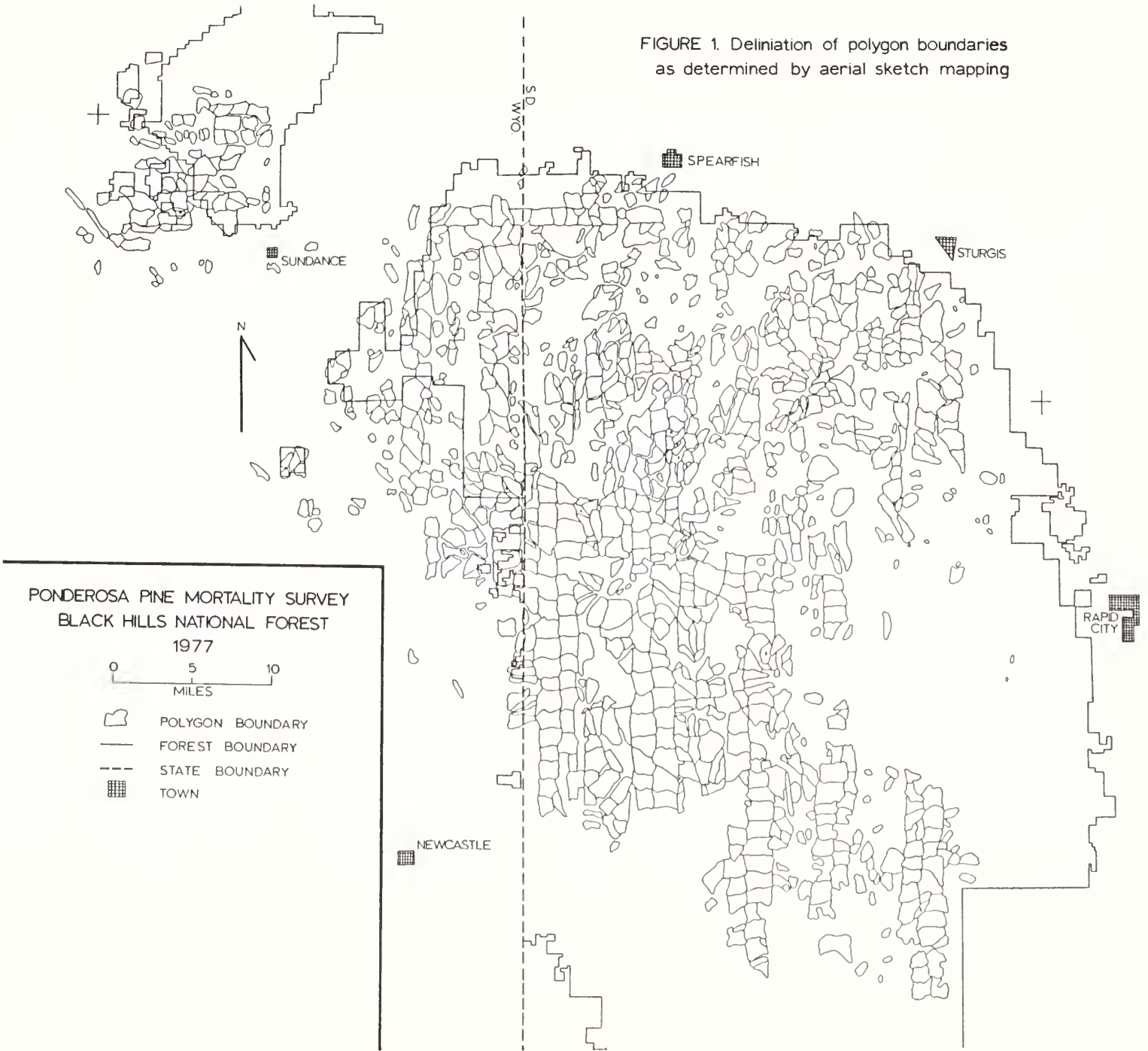

FIGURE 1. Deliniation of polygon boundaries as determined by aerial sketch mapping

Stratification

Subsequently, the area of each sketch mapped polygon was measured using a digitizing planimeter and then each polygon was placed into one of three strata based upon the number of discolored ponderosa pines (faders) per acre (Fig. 2 and Table 1). The strata used were: (1) less than 0.5 tree/acre (1.24 trees/ha); (2) 0.5 - 2.0 trees/acre (1.24 - 4.94 trees/ha); and (3) greater than 2 trees/acre (greater than 4.94 trees/ha). The total area covered by all of the polygons was about 475,000 acres (192,300 ha). These particular strata were selected in an attempt to establish three homogeneous land areas, thus reducing overall sampling variability.

Aerial Photography

Following the stratification procedures, photo plots (Fig. 3) were selected within each stratum along each flight line using an independent systematic random selection procedure. Flight lines were north-south and spaced one mile apart. Photo plots were selected for each strata with plot sizes of 90, 62.5, and 40 acres (36.4, 25.3, and 16.2 ha) assigned to the light, intermediate, and heavy strata respectively. Sample sizes for strata 1, 2, and 3 were 96, 71, and 65 respectively.

The photographs were taken on August 21-23, about 3 weeks after the photo plots were selected. A Cessna 180 and an Aero Commander were used to carry the photographic equipment. Each aircraft contained one of two camera types: a Fairchild KA-2 (12 in focal length) or a Zeiss RMK 21/23 (8¼ in focal length). Color aerial (Ektachrome 50-397) film 9x9-in (3.54 x 3.54 cm) stereo triplets were taken along flight lines at an approximate scale of 1:6,000. The altitude of the aircraft was recorded when flying over each of the photo plots.

The exposed film was processed by Precision Photo of Dayton, Ohio, and positive transparencies were obtained within 4 days. Each photo plot was assigned flight line and photo numbers and the location plotted on USGS topographic (1:24,000) and standard forest (1:126,720) maps. The difference between the elevation of the center of each plot and the altitude of the aircraft at the time each plot was photographed was used in determining photo scales.

A series of square acetate templates each representing 90 acres (36.4 ha) on a range of scales (1:5400 - 1:6600) were prepared. Each template was divided into 36 squares each representing a

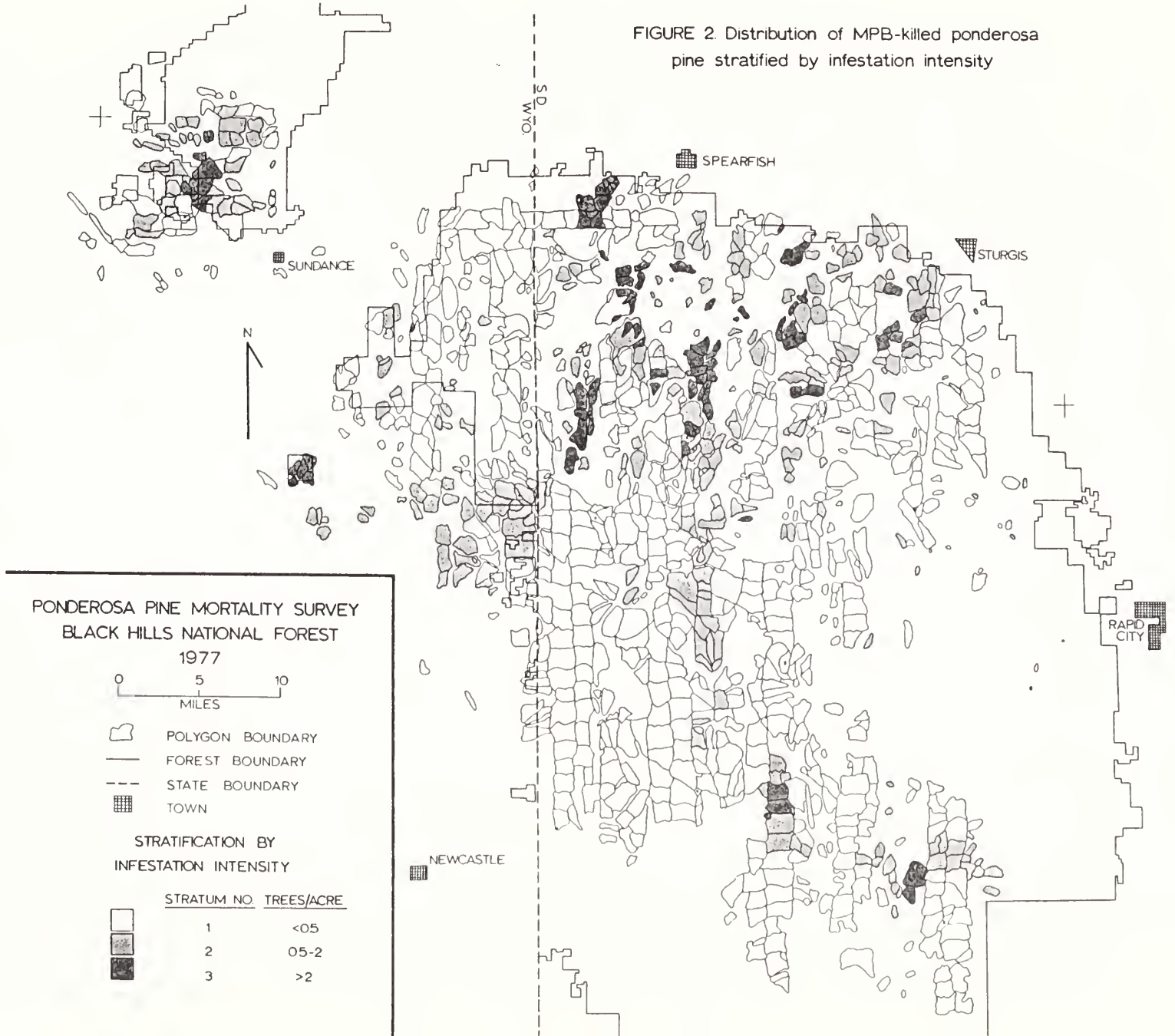

FIGURE 2. Distribution of MPB-killed ponderosa pine stratified by infestation intensity

Table 1. Stratification by intensity class of discolored *P. ponderosa* (i.e., faders) as determined from 1977 aerial sketch mapping in the Black Hills of South Dakota and Wyoming.

Stratum	Class boundaries (faders/acre)	Estimated No. of faders	Size of area (acres)	No. of polygons
1	< 0.5	63,545	353,984	646
2	0.5 - 2.0	83,175	92,095	285
3	> 2.0	106,810	28,132	94
Total		253,530	474,211	1,025

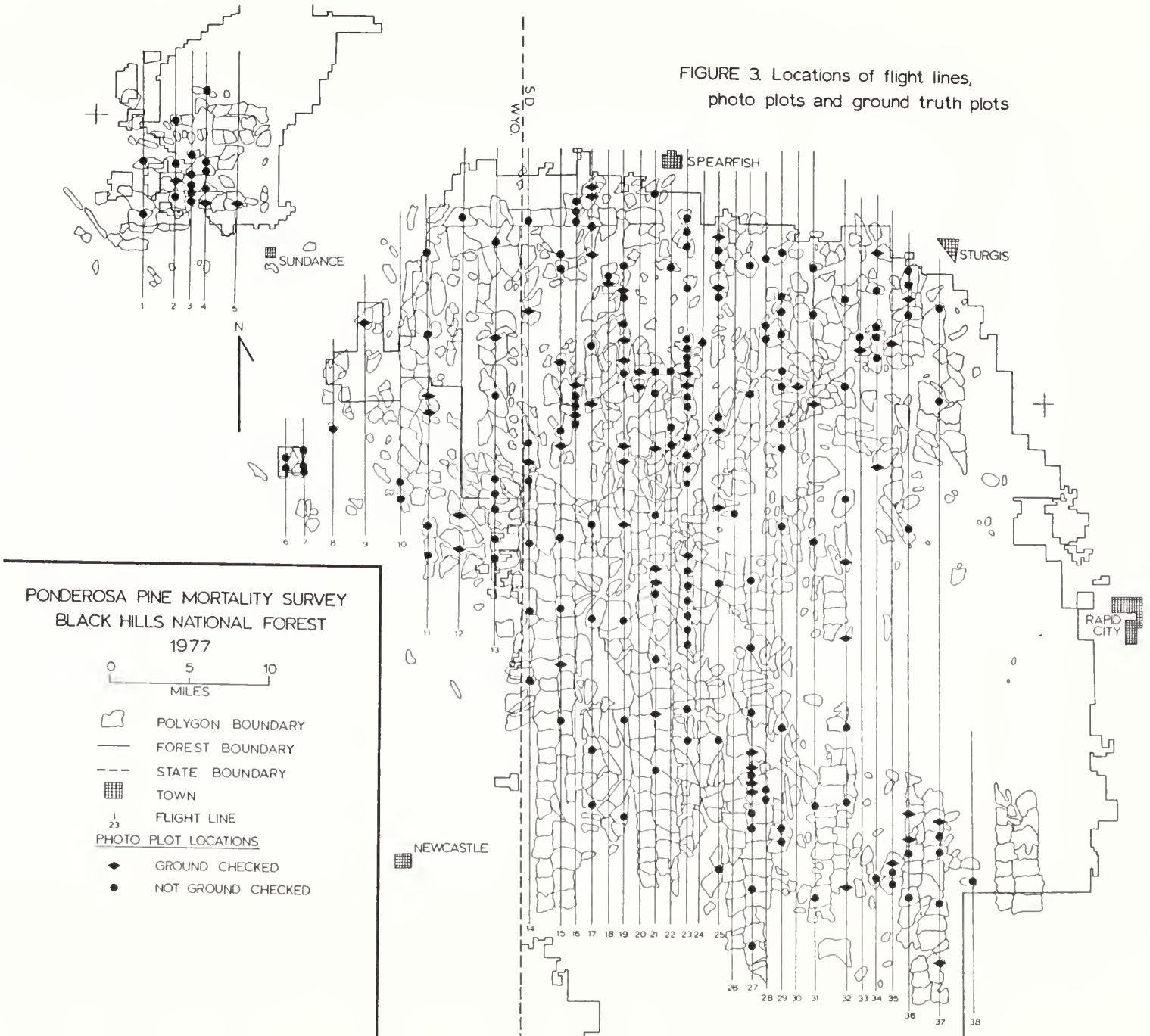

FIGURE 3. Locations of flight lines, photo plots and ground truth plots

2.5 acre (1.0 ha) subplot. A template of the proper scale was placed onto the center of the effective area of each of the 232 stereo pairs, each containing one photo plot.

Counts of faders were recorded for all 36 2.5-acre subplots for stratum 1 photo plots. Counts for strata 2 and 3 photo plots were recorded for the northwestern template squares of 25 and 16 subplots respectively. Fader counts were made by four photo interpreters using Old Delft scanning stereoscopes. Total time required for photo interpretation was approximately 10 days (40 person-days).

Ground Truth Acquisition

Twenty 2.5 acre (1.0 ha) ground check plots were randomly selected (without replacement) from the photo plots of each stratum (Fig. 3). The plot boundaries were then etched on the emulsion side of the film. Choosing the same number of plots from each stratum allowed the strata with greater tree mortality to be sampled more intensely since mortality density in the three strata was inversely related to total area of the strata.

Plots were located on the ground using 1:24,000 scale USGS topographic maps and stereo pairs. Transparencies of stereo pairs were placed into light-weight plastic film holders and examined with a pocket stereoscope using transmitted sunlight as the primary light source. If sunlight was below suitable illumination levels, it was supplemented with portable fluorescent lights.

Ground truth of all 60 plots was obtained during the period of September 15 - October 4. Crews of 2-3 people each located plots and marked plot boundaries with string. One-chain-wide strips within each plot were also marked with string to facilitate examination. Numbers of faders, snags, and 1977-attacked ponderosa pine 5 inches DBH and larger were recorded by 1-inch DBH class. Heights of at least 2 faders and/or snags in each DBH class were also recorded as well as the height of the first 1977-attacked tree measured in each diameter class.

Within each plot 5 variable radius plots were established with one located at ground plot center and one at each cardinal direction 2 chains from plot center. A Spiegal relaskop (BAF 10) on a Jacob staff was used to delineate plot boundaries within which were recorded, by species, all live trees 5 inches DBH and greater and all dead pines also 5 inches DBH and greater. The distance from plot center to tree center was measured for borderline trees.

This distance was compared to limiting distance tables to determine whether or not the tree was tallied. For each ground plot the elevation of ground-plot center and length of one boundary were measured as a check on scale accuracy.

Data Analysis

Data obtained were analyzed to determine estimates for: (1) the total number of faders from the aerial photo samples, (2) the relationship between counts of faders on the ground plots and those from corresponding photographs, and (3) the average volume per tree. Formulae used for estimating the above parameters are shown in Appendices B and C.

RESULTS

Correlations (see Appendix B) between numbers of faders determined from ground counts and from photo counts were good for strata 2 and 3 with coefficient of determination (R^2) values of 0.86 and 0.94 respectively. The R^2 value (0.69) for stratum 1 was considerably lower. Linear regression slope (b) estimates indicated that, in general, stratum 1 photo counts overestimated number of faders counted on the ground (b = 0.43), stratum 2 photo counts were approximately equal to ground counts (b = 1.06), and stratum 3 photo counts underestimated ground counts (b = 1.53).

The photo counts of faders from 19 of the 60 2.5-acre plots were greater than the ground counts, and 9 were less than the ground counts of the remaining 32 plots; however, 27 plots had zero-counts.

The relative standard errors of the double-sampling estimates of faders in each stratum decreased as the intensity of faders increased (Table 2), but stratum 3 still had 33.9 percent error, which is higher than is desirable (10% error or less) for our uses. The total number of faders estimated in the survey area was 293,181 $\pm$ 114,801 or about 0.62 faders/acre (0.25 faders/ha).

The double-sampling estimates of total fader volumes within each stratum were, likewise, not very precise (Table 2) with 132.9, 51.5, and 28.6 percent errors in strata 1-3 respectively. The estimated total volume of ponderosa pine killed was 5,380 $\pm$ 2,317 M cubic feet (Table 2) with an average volume per tree of 18.9 cubic feet.

Table 2. 1977 double-sampling estimates of numbers and volume of *P. ponderosa* killed in 1976 by *D. ponderosae* in an area of the Black Hills of South Dakota and Wyoming.

Stratum	Area (acres)	No. of faders [1/]	Standard error	Percent error	Volume [2/] per tree (cu. ft.)	Standard error	Total volume (M cu. ft.)	Standard error	Percent error
1	353,984	67,257	89,183	132.6	21.99	1.18	1,479	1,966	132.9
2	92,095	124,789	63,642	51.0	16.36	1.09	2,042	1,052	51.5
3	28,132	101,135	34,285	33.9	18.38	0.23	1,859	531	28.6
1+2+3	474,211	293,181	114,801	39.2	18.91		5,380	2,317	43.1

1/ See Appendix B for formulae used to compute these estimates.

2/ Volumes were calculated using information from Table 1, page 5 of: Meyers, C. A. 1964. Volume tables and point-sampling factors for ponderosa pine in the Black Hills. USDA Forest Service, Rocky Mt. For. and Range Exp. Sta. Res. Paper RM-8, 16 p.

A large part of the errors of the double-sampling estimates can be attributed to the fact that 27 of the 60 ground plots selected contained no faders.

Estimates of the number and volume of standing dead *P. ponderosa* were generated from ground-plot data only and, as expected, the standard errors were quite high (Table 3). The number of dead trees per acre for all strata combined was estimated to be about 3.13 and the total volume was determined to be 24,221 $\pm$ 9,751 M cubic feet or about 51 cubic feet per acre. Since these values were determined using only ground-plot data, they should be used with caution.

From variable plot data for strata 1-3, the basal area ratios of total dead to total living ponderosa pine were 0.04, 0.05, and 0.13 respectively (Table 4). The variable plot data were inadequate for obtaining a statistically valid estimate of the ratio of 1976-attacked to 1977-attacked trees.

DISCUSSION AND RECOMMENDATIONS

Stratification into intensity classes seems to be a reasonable approach for improving estimates of ponderosa pine killed by the mountain pine beetle since trees are usually killed in groups and other nonrandom patterns. In this project, stratification did not reduce population variance as much as we expected probably due to the randomized plot selection method that was used. This method resulted in too many plots which contained no faders.

The estimates of the numbers of faders in each intensity class using sketch mapping, double-sampling, and photo plots (Table 5) seem to become more congruous as the intensity increases and the relative standard errors seem to decrease. Thus, in future surveys it may be wise to eliminate the lowest intensity class from use in this multistage sampling procedure.

Similar but modified surveys should be conducted in 1978 in ponderosa pine in the Black Hills National Forest of South Dakota and Wyoming. Significant modifications recommended are:

1. Two strata should be used instead of three.

Table 3. Estimates from ground-plot data of numbers and volume of standing, dead *P. ponderosa* killed by *D. ponderosae* before 1976.

Stratum	No. of dead trees	No. of dead trees/acre	Volume of dead trees (M cu. ft.)	Volume/tree (cu. ft.)
1	987,000	2.79	15,527 ± 9,249	15.74
2	366,000	3.98	3,782 ± 1,562	10.33
3	129,000	4.60	4,892 ± 2,665	15.37
Total	1,482,000	3.13	24,221 ± 9,751	14.38

Table 4. Estimates of percent total basal area by tree species in 1977 survey area of the Black Hills of South Dakota and Wyoming.

Stratum	*P. ponderosa* Living	*P. ponderosa* Dead	*Picea glauca*	Other species	Total
1	82.6	3.5	11.5	2.4	100.0
2	86.1	4.5	6.6	2.8	100.0
3	83.9	11.1	1.1	3.9	100.0

Table 5. Numbers of faders determined by three methods in the 1977 survey area of the Black Hills of South Dakota and Wyoming.

Stratum	Estimation Method: Sketch mapping	Double Sampling [1]	Photo Interpretation
1	63,545	67,257 (132.6)	171,609 (13.5)
2	83,175	124,789 (51.0)	156,735 (14.8)
3	106,810	101,135 (33.9)	84,970 (14.3)
Total	253,530	293,181 (39.2)	413,314 (8.5)

[1] numbers in parentheses are relative standard errors expressed as percentages

2. Photo and plot selection should be done using the probability proportional to size procedure. This procedure greatly reduces the probability of selecting plots with no faders.

3. Approximately 100 photo plots should be selected from the high intensity stratum and 75 from the low intensity stratum. Photo plots should be selected using a systematic random procedure.

4. Fifty ground plots should be chosen from each stratum. Two ground plots should be chosen from each of 25 photos that are selected from each stratum.

5. Medium-scale (maximum 1:30,000) high resolution panoramic (i.e., optical bar) (5x50-in) CIR photography should be taken, as well as the large scale (1:6,000) color photography, to test the large format film for use in stratification and direct sampling. If it proves to be adequate, this photography method could lower survey costs and amount of time spent conducting the survey.

We feel that the above recommendations will greatly improve the design of the Black Hills tree-mortality survey. In addition, with minor modifications this survey design may be applicable to surveys of bark beetle-caused tree mortality in other areas with the same or different tree species.

DISCLAIMER STATEMENT

The use of trade, firm, or corporation names is for the information and convenience of the reader. Such use does not constitute an official evaluation, conclusion, recommendation, endorsement, or approval of any product or service to the exclusion of others which may be suitable.

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Appendix A. Time table for the 1977 ponderosa pine mortality survey in the Black Hills of South Dakota and Wyoming.

	ACTIVITY	DATES
1.	Draft Work Plan Completion	March 1
2.	Final Work Plan Completion	April 15
3.	Purchase of Film & Equipment	March 1 - 15
4.	MAG - Region Coord. Meeting	March 14 - 15
5.	Aerial Sketch mapping	
	a. Sketch mapping	August 2 - 6
	b. Digitizing	August 3 - 6
	c. Strata Determination	August 18
6.	Aerial Photography	
	a. Planning, Plot and Flight Line Determination	August 10 - 18
	b. Photo Crew Orientation	August 20
	c. Aerial Photography	August 21 - 23
	d. Film Shipment & Process	August 23 - 26
	e. Annotation & Organization	August 27 - 29
7.	Photo Interpretation	
	a. Training	September 5
	b. Photo Interpretation	September 5 - 14
	c. Aerial Confirmation	September 6 - 9
8.	Ground Surveys	
	a. Training	September 12 - 14
	b. Ground Truth Acquisition	September 15 - October 4
	c. Additional Data Gathering	October 8 - 12
9.	Data Compulation	September 13 - October 14
10.	Data Analysis	October 17 - December 2

Appendix B. Formulae used for calculating linear regression and double sampling estimates for each stratum.

Note: The linear regression and double-sampling estimates were based on matched data pairs of faders per acre on-the-ground and on photos of the 2.5-acre randomly selected subplots.

Regression estimates of slope (b) and y-intercept (a) [1/]

$$b = \frac{\Sigma x_i y_i - \frac{(\Sigma x_i \, \Sigma y_i)}{n}}{\Sigma x_i^2 - \frac{(\Sigma x_i)^2}{n}}$$

$$a = \bar{y} - b\bar{x}$$

where, n = number of data pairs

x_i = number of faders counted on photo in i^{th} subplot

y_i = number of faders counted on ground in i^{th} subplot

$$\bar{x} = \frac{\Sigma x_i}{n}$$

$$\bar{y} = \frac{\Sigma y_i}{n}$$

Double sampling estimate of faders per acre ($\hat{\bar{Y}}$)

$$\hat{\bar{Y}} = \bar{y} + b (\bar{x}' - \bar{x})$$

where, $\bar{x}'$ = mean number of faders per acre counted on the large photo samples

1/ Calculations were made for each stratum.

Appendix B. (continued)

Standard error of $\hat{\bar{Y}}$ (S.E. $\hat{\bar{Y}}$)

$$\text{S.E. } \hat{\bar{Y}} = \sqrt{S^2_{y \cdot x} \left[\frac{1}{n} + \frac{(\bar{x}' - \bar{x})^2}{\Sigma (x_i - \bar{x})^2} \right] + \frac{S^2y - S^2y \cdot x}{m}}$$

$$\text{where, } S^2y \cdot x = \frac{1}{n-2} \left[\Sigma (y_i - \bar{y})^2 - b^2 \Sigma (x_i - \bar{x})^2 \right]$$

$$S^2y = \frac{\Sigma (y_i - \bar{y})^2}{n - 1}$$

m = the number of large photo samples

Appendix C. Formulae for estimating total number of faders per stratum using only the photo interpretation counts.

Total number of faders ($\hat{X}$)

$$\hat{X} = \frac{M}{m} \sum_{i=1}^{m} x_i$$

where, M = total number of sampling units possible in the stratum.(i.e., total acres divided by the size of the sampling unit)

m = sample size (i.e., number of photo plots selected for photo interpretation)

x_i = number of faders counted in the i^{th} photo plot

Standard error of $\hat{X}$ (S.E. $_{\hat{X}}$)

$$\text{S.E.}_{\hat{X}} = \sqrt{M^2 \left[\frac{M-m}{M}\right] \left[\frac{\sum x_i^2 - \frac{(\sum x_i)^2}{m}}{m\,(m-1)}\right]}$$

Relative standard error (R.S.E. $_{\hat{X}}$)

$$\text{R.S.E.}_{\hat{X}} = \frac{\text{S.E.}_{\hat{X}}}{\hat{X}}$$

Percent standard error = (R.S.E. $_{\hat{X}}$) (100)